

Timelike Compton Scattering in Ultraperipheral Collisions

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Exclusive photoproduction of dileptons, $\gamma N \rightarrow \ell^+ \ell^- N$, is and will be measured in ultraperipheral collisions at hadron colliders. We demonstrate that the timelike deeply virtual Compton scattering (TCS) mechanism $\gamma q \rightarrow \ell^+ \ell^- q$, where the lepton pair comes from the subprocess $\gamma q \rightarrow \gamma^* q$, dominates in some accessible kinematical regions, thus opening a new way to study generalized parton distributions (GPD) in the nucleon at small skewedness.

1 Introduction.

Much theoretical and experimental progress has recently been witnessed in the study of deeply virtual Compton scattering (DVCS), i.e., $\gamma^* p \rightarrow \gamma p$, an exclusive reaction where generalized parton distributions (GPDs) factorize from perturbatively calculable coefficient functions, when the virtuality of the incoming photon is high enough [2]. It is now recognized that the measurement of GPDs should contribute in a decisive way to our understanding of how quarks and gluons build hadrons [3]. In particular the transverse location of quarks and gluons become experimentally measurable via the transverse momentum dependence of the GPDs [4]. In our work [5] we study the "inverse" process,

$$\gamma(q)N(p) \rightarrow \gamma^*(q')N(p') \rightarrow l^-(k)l^+(k')N(p')$$

at small $t = (p' - p)^2$ and large *timelike* virtuality $(k + k')^2 = q'^2 = Q'^2$ of the final state dilepton, timelike Compton scattering (TCS) [6], which shares many features with DVCS.

The possibility to use high energy hadron colliders as powerful sources of quasi real photons in ultraperipheral collisions has recently been emphasized [7]. This should allow the study of many aspects of photon proton and photon photon collisions at high energies, already at the Tevatron and at RHIC but in particular at the LHC [8]

even if the nominal luminosity is not achieved during its first years of operation. The high luminosity and energies of these photon beams opens a new kinematical domain for the study of TCS, and thus to the hope of determining GPDs in the small skewedness (ξ)

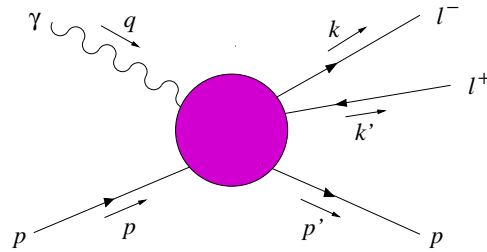


Figure 1: Real photon-proton scattering into a lepton pair and a proton.

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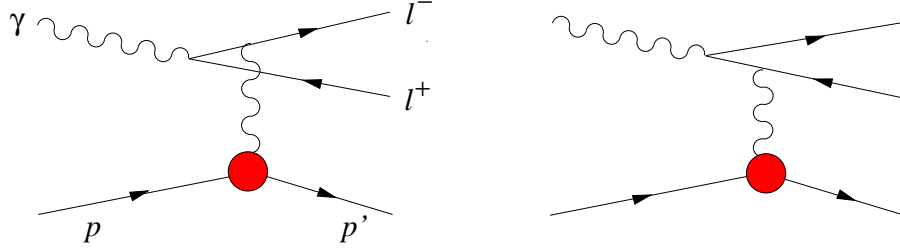


Figure 2: The Feynman diagrams for the Bethe-Heitler amplitude.

region, which is complementary to the determination of the large ξ quark GPDs at lower energy electron accelerators such as JLab. Moreover, the crossing from a spacelike to a timelike probe is an important test of the understanding of QCD corrections, as shown by the history of the understanding of the Drell-Yan reaction in terms of QCD.

2 Photoproduction of a lepton pair

The physical process where to observe TCS, is photoproduction of a heavy lepton pair, $\gamma N \rightarrow \mu^+ \mu^- N$ or $\gamma N \rightarrow e^+ e^- N$, shown in Fig. 1. As in the case of DVCS, the Bethe-Heitler (BH) mechanism contributes at the amplitude level. This process has a very peculiar angular dependence and overdominates the TCS process if one blindly integrates over the final phase space. One may however choose kinematics where the amplitudes of the two processes are of the same order of magnitude, and either subtract the well-known Bethe-Heitler process or use specific observables sensitive to the interference of the two amplitudes. The Bethe-Heitler amplitude is calculated from the two Feynman diagrams in Fig. 2. Neglecting masses and t compared to terms going with s or Q'^2 , the Bethe Heitler contribution to the unpolarized γp cross section is (M is the proton mass)

$$\frac{d\sigma_{BH}}{dQ'^2 dt d\cos\theta} \approx 2\alpha^3 \frac{1}{-tQ'^4} \frac{1 + \cos^2\theta}{1 - \cos^2\theta} \left(F_1(t)^2 - \frac{t}{4M_p^2} F_2(t)^2 \right), \quad (1)$$

provided we stay away from the kinematical region where the product of lepton propagators goes to zero at very small θ ($F_1(t)$ and $F_2(t)$ are Dirac and Pauli nucleon form factors). The

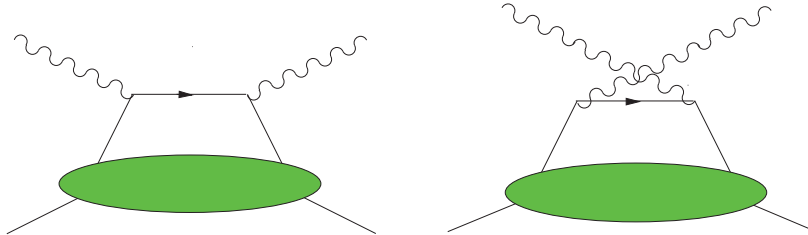


Figure 3: Handbag diagrams for the Compton process in the scaling limit.

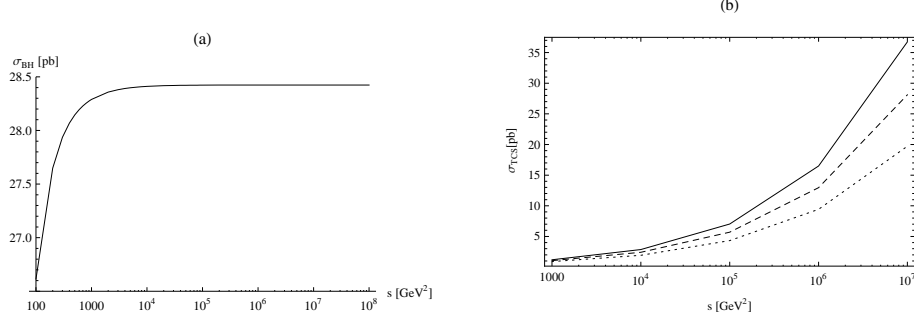


Figure 4: a) The BH cross section integrated over $\theta \in [\pi/4, 3\pi/4]$, $\varphi \in [0, 2\pi]$, $Q'^2 \in [4.5, 5.5] \text{ GeV}^2$, $|t| \in [0.05, 0.25] \text{ GeV}^2$, as a function of γp c.m. energy squared s . b) σ_{TCS} as a function of γp c.m. energy squared s , for GPD parametrization based on the GRVGJR2008 NLO PDF, for different factorization scales $\mu_F^2 = 4$ (dotted), 5 (dashed), 6 (solid) GeV^2 .

interesting physics program thus imposes a cut on θ to stay away from the region where the Bethe Heitler cross section becomes extremely large.

In the region where the final photon virtuality is large, the Compton amplitude is given by the convolution of hard scattering coefficients, calculable in perturbation theory, and generalized parton distributions, which describe the nonperturbative physics of the process. To leading order in α_s one then has the dominance of the quark handbag diagrams of Fig. 3.

$$\frac{d\sigma_{TCS}}{dQ'^2 d\Omega dt} \approx \frac{\alpha^3}{8\pi} \frac{1}{s^2} \frac{1}{Q'^2} \left(\frac{1 + \cos^2 \theta}{4} \right) 2(1 - \eta^2) \left(|\mathcal{H}|^2 + |\tilde{\mathcal{H}}|^2 \right), \quad (2)$$

where \mathcal{H} and $\tilde{\mathcal{H}}$ are Compton formfactors, defined as in [6], and η is the skewedness parameter related to the Bjorken variable $\tau = Q'^2/s$ by $\eta = \tau/(2 - \tau)$. Full BH and TCS cross section as a functions of c.m. energy squared s are shown on Fig. 4. Since the amplitudes for the Compton and Bethe-Heitler processes transform with opposite signs under reversal of the lepton charge, it is possible to project out the interference term through a clever use of the angular distribution of the lepton pair. The interference part of the cross-section for $\gamma p \rightarrow \ell^+ \ell^- p$ with unpolarized protons and photons is given at leading order by

$$\frac{d\sigma_{INT}}{dQ'^2 dt d\cos\theta d\varphi} = - \frac{\alpha_{em}^3}{4\pi s^2} \frac{1}{-t} \frac{M}{Q'} \frac{1}{\tau \sqrt{1 - \tau}} \cos\varphi \frac{1 + \cos^2 \theta}{\sin\theta} \text{Re } \tilde{M}^{--}, \quad (3)$$

with $(-t_0 = 4\eta^2 M^2/(1 - \eta^2))$:

$$\tilde{M}^{--} = \frac{2\sqrt{t_0 - t}}{M} \frac{1 - \eta}{1 + \eta} \left[F_1 \mathcal{H}_1 - \eta(F_1 + F_2) \tilde{\mathcal{H}}_1 - \frac{t}{4M^2} F_2 \mathcal{E}_1 \right]. \quad (4)$$

Figure 5 shows the interference contribution to the cross section in comparison to the Bethe Heitler and Compton processes, for various values of c.m. energy squared $s = 10^7 \text{ GeV}^2, 10^5 \text{ GeV}^2, 10^3 \text{ GeV}^2$. We observe that for large energies the Compton process dominates, whereas for $s = 10^5 \text{ GeV}^2$ all contributions are comparable.

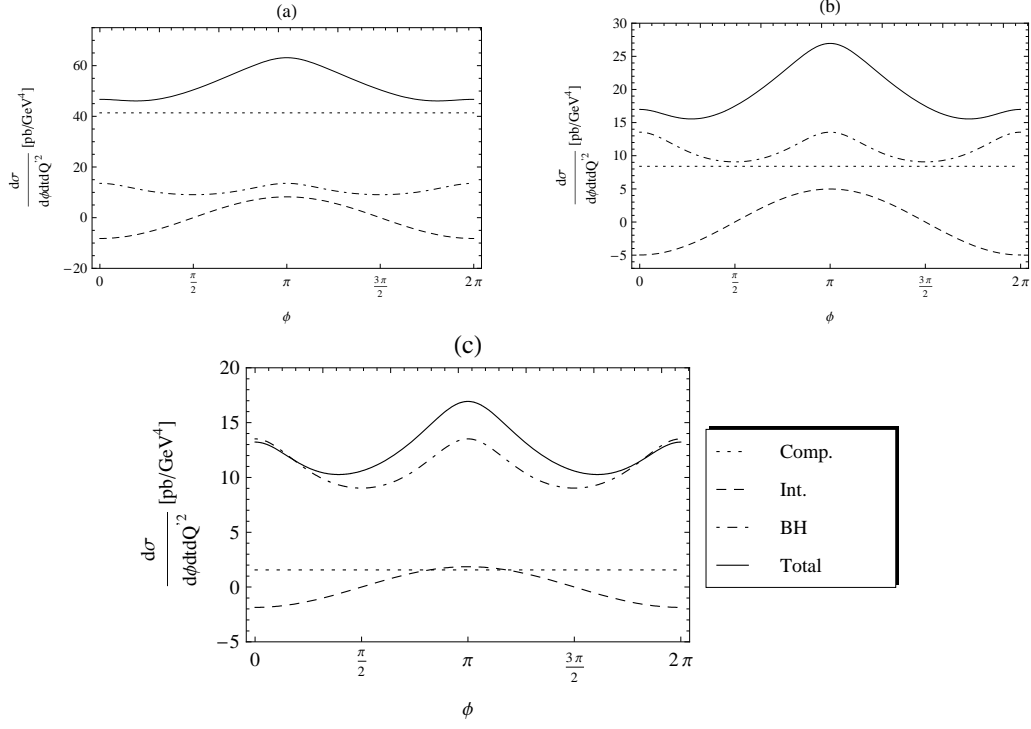


Figure 5: The differential cross sections (solid lines) for $t = -0.2 \text{ GeV}^2$, $Q'^2 = 5 \text{ GeV}^2$ and integrated over $\theta = [\pi/4, 3\pi/4]$, as a function of φ , for $s = 10^7 \text{ GeV}^2$ (a), $s = 10^5 \text{ GeV}^2$ (b), $s = 10^3 \text{ GeV}^2$ (c) with $\mu_F^2 = 5 \text{ GeV}^2$. We also display the Compton (dotted), Bethe-Heitler (dash-dotted) and Interference (dashed) contributions.

3 Full cross section

The cross section for photoproduction in hadron collisions is given by:

$$\sigma_{pp} = 2 \int \frac{dn(k)}{dk} \sigma_{\gamma p}(k) dk \quad (5)$$

where $\sigma_{\gamma p}(k)$ is the cross section for the $\gamma p \rightarrow pl^+l^-$ process and k is the photon energy. $\frac{dn(k)}{dk}$ is an equivalent photon flux. The relationship between γp energy squared s and k is given by $s \approx 2\sqrt{s_{pp}}k$, where s_{pp} is the proton-proton energy squared ($\sqrt{s_{pp}} = 14 \text{ TeV}$)

The Bethe - Heitler contribution to σ_{pp} , integrated over $\theta = [\pi/4, 3\pi/4]$, $\phi = [0, 2\pi]$, $t = [-0.05 \text{ GeV}^2, -0.25 \text{ GeV}^2]$, $Q'^2 = [4.5 \text{ GeV}^2, 5.5 \text{ GeV}^2]$, and photon energies $k = [20, 900] \text{ GeV}$ gives:

$$\sigma_{pp}^{BH} = 2.9 \text{ pb} . \quad (6)$$

The Compton contribution (calculated with NLO GRVGJR2008 PDFs, and $\mu_F^2 = 5 \text{ GeV}^2$) gives:

$$\sigma_{pp}^{TCS} = 1.9 \text{ pb} . \quad (7)$$

We have chosen the range of photon energies in accordance with expected capabilities to tag photon energies at the LHC. This amounts to a large rate of order of 10^5 events/year at the LHC with its nominal luminosity ($10^{34} \text{ cm}^{-2} \text{ s}^{-1}$).

4 Conclusions

Timelike Compton scattering in ultraperipheral collisions at hadron colliders opens a new way to measure generalized parton distributions. We have found sizeable rates of events at LHC, even for the lower luminosity which can be achieved in the first months of run. Our work has to be supplemented by studies of higher order contributions which will involve the gluon GPDs.

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References

- [1] Slides:
<http://indico.cern.ch/contributionDisplay.py?contribId=178&sessionId=18&confId=53294>
- [2] D. Müller *et al.*, Fortsch. Phys. **42**, 101 (1994); X. Ji, Phys. Rev. Lett. **78**, 610 (1997); A. V. Radyushkin, Phys. Rev. **D56**, 5524 (1997); J. C. Collins and A. Freund, Phys. Rev. **D59**, 074009 (1999).
- [3] M. Diehl, Phys. Rept. **388** (2003) 41; A. V. Belitsky and A. V. Radyushkin, Phys. Rept. **418**, 1 (2005); S. Boffi and B. Pasquini, Riv. Nuovo Cim. **30**, 387 (2007).
- [4] M. Burkardt, Phys. Rev. D **62**, 071503 (2000) and Int. J. Mod. Phys. A **18**, 173 (2003); J. P. Ralston and B. Pire, Phys. Rev. D **66**, 111501 (2002); M. Diehl, Eur. Phys. J. C **25**, 223 (2002).
- [5] B. Pire, L. Szymanowski and J. Wagner, Phys. Rev. D **79** (2009) 014010, and Nucl. Phys. Proc. Suppl. **179-180**, 232 (2008).
- [6] E. R. Berger, M. Diehl and B. Pire, Eur. Phys. J. C **23**, 675 (2002).
- [7] K. Hencken *et al.*, Phys. Rept. **458**, 1 (2008).
- [8] D. d’Enterria, M. Klasen and K. Piotrkowski, Nucl. Phys. Proc. Suppl. B **179**, 1 (2008); B. Pire, L. Szymanowski, F. Schwennsen and S. Wallon, arXiv:0810.3817 [hep-ph].